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TENSILE PROPERTIES OF AW AND PWHT PN-229 WELD METALS IN THE TEMPERATURE RANGE 20-350°C UNDER CONSTANT APPLIED STRAIN RATE CONDITIONS - SUPPLEMENTARY STUDY

Report No. 88-154-K

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ABSTRACT

A supplementary tensile test program has been carried out to more fully characterize the plastic flow behaviour of both as-welded (AW) and postweld heat treated (PWHT) PN-229 weld metals over the temperature range 20-350°C. At each temperature, the samples were deformed under a constant applied strain rate of 1×10^{-3} s^{-1}. Results obtained indicate that both AW and PWHT materials were susceptible to serrated flow, with the former material being much more prone to this manifestation of dynamic strain aging. The supplementary data show that the tensile strength of the AW material begins to increase with increasing temperature at about 100°C and peaks at about 200°C, although serrated flow only commences at about 150°C. Furthermore, the new data clearly show that the tensile strength vs temperature plot for the PWHT material exhibits local minimum and maximum values at about 200 and 350°C, respectively. The data also show that the PWHT material exhibits a shallow minimum in ductility at about 300°C. Based on this more complete data set, the AW and PWHT materials should exhibit minimum fracture toughness properties at temperatures in the range 150-200°C and 300-350°C, respectively.

job	file	date	report no.
84-535-050	823.422	July 27, 1988	88-154-K

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EXECUTIVE SUMMARY

TENSILE PROPERTIES OF AW AND PWHT PN-229 WELD METALS IN THE TEMPERATURE RANGE 20-350°C UNDER CONSTANT APPLIED STRAIN RATE CONDITIONS - SUPPLEMENTARY STUDY

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OBJECTIVE:

The main objective of the study was to characterize more fully the plastic flow behaviour of as-welded (AW) and postweld heat treated (PWHT) PN-229 weld metals over the temperature range 20-350°C by carrying out additional tensile tests which supplement the data obtained in a previous study. This information, together with data obtained previously from other studies of the overall Darlington leak-before-break material test program, can then be used to perform detailed material integrity assessments of the Darlington PHT piping system.

MAJOR RESULTS OF STUDY:

1. Both AW and PWHT PN-229 weld materials were susceptible to serrated flow. The AW material exhibits serrated flow behaviour at temperatures in the range 150-250°C while the PWHT material exhibits considerably reduced serrated flow behaviour in the temperature range 200-250°C.

2. The supplementary data show that the tensile strength of the AW material begins to increase with increasing temperature at about 100°C and peaks at about 200°C although serrated flow was observed to commence at about 150°C.

3. The new data show clearly that the tensile strength vs temperature plot for the PWHT material exhibits local minimum and maximum values at about 200 and 350°C, respectively.

4. Based on this more complete data set, the AW and PWHT materials should exhibit minimum fracture toughness properties at temperatures in the range 150-200°C and 300-350°C, respectively.

RECOMMENDATION

1. A few additional fracture toughness tests should be carried out using PWHT material at temperatures in the range 300-350°C.

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To Dr. D. Mills
Director of Research

TENSILE PROPERTIES OF AW AND PWHT PN-229 WELD METALS IN THE TEMPERATURE RANGE 20-350°C UNDER CONSTANT APPLIED STRAIN RATE CONDITIONS - SUPPLEMENTARY STUDY

1.0 INTRODUCTION

In a recently completed test program/1/, the plastic flow behaviour of both as-welded (AW) and postweld heat treated (PWHT) PN-229 weld materials was investigated. The work carried out was part of an overall OHRD test program to evaluate the effect of postweld heat treatment on the toughness of weldments in SA106B piping material. The main objective of the above study was to characterize the serrated flow behaviour of the AW and PWHT PN-229 weld materials in particular, and the plastic flow behaviour in general. However, due to financial and time constraints, only a limited range of temperatures could be investigated in detail. Results obtained indicate that a supplementary program is required to more fully characterize the flow behaviour of the AW and PWHT materials over the temperature range 20-350°C.

The current study was undertaken to accomplish the above-mentioned objective. The recent acquisition of a high temperature extensometer enabled us to monitor more precisely the deformation of the gauge length of the tensile specimens. In the two previous studies/1,2/, the true stress-strain data had to be calculated from records of the sample load vs ram displacement data and a calibration sample load vs ram displacement data set. As described previously/3/, this technique did not produce consistently good elastic stress-strain data.

2.0 EXPERIMENTAL

The material used in this supplementary test program was designated as coupon 2A in the previous study/1/. The weld procedure used to fabricate this coupon has been documented elsewhere/4/. It is essentially a modification of Ontario Hydro weld procedure PN-229-85 and was implemented in an attempt to obtain improved weld metal mechanical properties.

Tensile specimens were machined from sections of the weld coupon 2A in such a manner that the tensile axis is parallel to the pipe axis and located at the 1/4-depth position relative to the pipe OD surface. The nominal dimensions of the sample gauge length were 4.57 mm (0.180") in diameter and 19.05 mm (0.75") in length. This selection of subsize specimen geometry was chosen to ensure that the sample gauge length was comprised entirely of weld metal. The samples were machined in conformance to ASTM specifications for round subsize specimens.

The PWHT was accomplished by wrapping machined tensile specimens in two layers of Sen Pac and placing them in a resistance furnace. In the previous study/1/, the PWHT was done by placing sections of the weld coupons in a resistance furnace prior to machining into tensile specimens. The heat treatment consisted of two (2) hours at 620°C.

The tensile testing was carried out using a computer-controlled MTS servohydraulic Materials Test System, as was the case for the two previous studies/1,2/. However, for the present test program, a newly acquired high temperature extensometer was used for strain measurement. The new JVK high temperature extensometer has been described in detail elsewhere/5/.

As was the case in the companion study/1/, the samples were deformed under constant applied strain rate conditions. In addition, a continuous record of the load cell and ram displacement analog voltages was made using an X-Y chart recorder, together with a discrete digitized record of the extensometer output voltage as well as the above two voltages. The continuous record of load cell vs ram displacement provides a means to completely characterize the serrated flow behaviour when it occurs.

3.0 RESULTS

A summary of the tensile data obtained in the present study is presented in Table I. The table also contains some data obtained previously for both 1A and 2A coupon materials. The data obtained from these two weld coupons were previously found to be indistinguishable/1/. Plots of 0.2% offset yield and tensile strengths with temperature for AW and PWHT materials are presented in Figures 1 and 2, respectively. The plots show clearly that the tensile strength of the AW material is a maximum at about 200°C for an applied strain rate of 1×10^{-3} s^{-1}. In comparison, the tensile strength of the PWHT material is minimum at about the same temperature. However, the tensile strength vs temperature curve for the PWHT material also exhibits a peak at about 350°C. Plots illustrating the variation of %RA and % elongation with temperature for AW and PWHT materials are shown in Figures 3 and 4, respectively. The data show clearly that the %RA and %elongation of the AW material exhibit minimum at about 200 and 150°C, respectively. In comparison, the % RA and % elongation of the PWHT material exhibit minimum values at about 350 and 300°C, respectively. The magnitudes of these two latter extremal values, however, were much larger than those observed for the AW material.

4.0 DISCUSSION OF RESULTS

4.1 General

In a previous study/1/, the plastic flow behaviour of both AW and PWHT PN-229 weld materials was investigated. Test temperatures of 20, 150, 200, 250 and 300°C and constant applied strain rates of 1×10^{-2}, 1×10^{-3} and 1×10^{-4} s^{-1} were used. However, due to time and financial constraints, only test temperatures of 200, 250 and 300°C were investigated in detail (ie, at the three different applied strain rates) for the AW material and at 200 and 300°C for the PWHT material. Serrated or jerky flow was observed in tensile testing of both types of materials. The occurrence of serrated flow was found to be most prevalent in AW material at temperatures in the range 150-200°C. Moreover, the flow stress of the AW material was observed to be negative strain rate sensitive in the above temperature range, with the magnitude of the negative rate sensitivity greater at the lower temperature. The AW material exhibits a maximum in tensile strength at about 200°C and a minimum in ductility (ie, % RA and % elongation) at approximately the same temperature, at all three applied strain rates investigated.

Unfortunately, insufficient data were obtained for the PWHT material to establish the dependence of the tensile strength on applied strain rate and test temperature. The main finding for the PWHT material was that the postweld heat treatment used did not completely eliminate serrated flow, but did apparently eliminate sufficient free interstitial solutes from solid solution to give the PWHT material much better ductility. The PWHT also reduced the tensile and yield strengths of the weld material substantially.

As noted in the Introduction, the current study was undertaken to supplement the study described briefly above. To achieve this objective, test temperatures of 20, 60, 100, 125, 150, 200, 250, 300 and 350°C were examined for the AW material and temperatures of 20, 60, 100, 150, 200, 250, 300, 350 and 400°C were investigated for the PWHT material. However, only the intermediate applied strain rate of 1×10^{-3} s^{-1} was used. The previous study had shown that the flow stress and serrated flow behaviour were dependent on both temperature and applied strain rate. For this study, the intermediate applied strain rate of 1×10^{-3} s^{-1} was chosen because this deformation rate is within the post-yield strain rate range recommended by ASTM Specification E21/6/ for elevated temperature tension tests.

Results obtained from previous studies of parent SA106B piping material/2/ and PN-229 weld material/1/ indicate that there is a correlation between tensile properties such as tensile strength and % RA, and fracture toughness. In particular, for the above materials, it was observed that in a temperature regime where the material exhibits a local maximum in tensile strength and a local minimum in % RA, it also shows a minimum in fracture toughness. This observation is especially valid if the peak in flow stress can be attributed to dynamic strain aging.

4.2 Variation of Yield Strength with Temperature

The variation of yield strength with temperature for the AW and PWHT materials are shown in Figure 1 and 2, respectively. As shown in Figure 1, the 0.2% offset yield strength of the AW material decreases continuously with increasing test temperature. The yield strength vs temperature plot contains two approximately linear regions: a smaller slope region between 20 and 200°C and a larger slope region between 200 and 350°C. The change in slope occurs at about the temperature where the tensile strength vs temperature plot exhibits a maximum.

The yield strength of the PWHT material also decreases with increasing test temperature. From ambient temperature to 250°C, the incremental change or decrease in the yield strength increases with increasing temperature. From 250°C to 350°C, the decrease in yield strength is linear and the rate of decrease is minimal (ie, smaller than the initial rate of decrease found at ambient temperature). From 350°C to 400°C, the rate of decrease is similar to that found between 100°C and 150°C.

From the above discussion and the data presented in Figures 1 and 2, it is apparent that the yield stress of both AW and PWHT materials is very weakly dependent on temperature in the temperature regime where the flow stress increases with increasing temperature. Such behaviour for the yield stress has been observed previously in parent SA106B piping material/2/ and in other mild to medium carbon steels/7-9/. This type of behaviour has been attributed to an athermal stress which could arise from long-range internal stresses due to dislocations or from internal stress fields due to solute atoms.

4.3 Variation of Tensile Strength with Temperature

The variation of the tensile strength with temperature in the AW material is presented in Figure 1. The plot shows clearly that there is a local maximum at about 200°C, which had been deduced previously from less complete tensile data. It is interesting to note that the rapid increase in tensile strength with temperature begins at about 100°C whereas serrated flow only commences at about 150°C. The particular shape of the above tensile strength vs temperature curve has been observed in some heats of SA515 Grade 70 pressure vessel steels/7/ and in simulated as-welded repair weld metals/8/ using consumables ranging from C-Mn to Mn-Ni-Cr-Mo types which are suitable for pressure vessel repairs. In each case, dynamic strain aging was mainly responsible for the observed flow behaviour with temperature.

The variation of the tensile strength with temperature in PWHT material is shown in Figure 2. The plot exhibits extremal values at about 200 and 350°C. Such variations of the tensile strength with temperature have been observed in a wide variety of medium carbon steels such as SA106B piping material/2/ and SA515 Grade 70 pressure vessel steels/7/. The above variations with temperature may be attributed to interstitial solute-dislocation interactions and the temperature dependence of the mobility of the interstitial solute atoms. The temperature regime where the tensile strength is higher than that observed at ambient temperature coincides with the temperature range where the solute-dislocation interactions are strong/10/.

4.4 Variations of Percent Reduction of Area and Percent Elongation with Temperature

The variation of the % RA and the % elongation with temperature in AW material are shown in Figure 3. The % RA vs temperature curve shows a relatively wide minimum at temperatures in the range 150-250°C, the temperature regime in which serrated flow was observed. Such co-existence of serrated flow and minimal % RA has been reported by other workers/7,11-13/ for mild to medium carbon steels and weldments in such steels.

The variation of the % elongation parameter with temperature for AW material is also presented in Figure 3. The curve shows clearly that there is a local minimum at about 150°C. Similar results have been reported by Bailey/8/ for a number of simulated as-welded repair weld deposits in C-Mn and Mn-Ni-Mo steels.

The variation of the % RA parameter with temperature for the PWHT material is shown in Figure 4. The data show clearly that there is a very shallow minimum at about 350°C. Similarly, the % elongation vs temperature curve for the PWHT material exhibits a shallow minimum at about 300°C. Above 300°C, the % elongation increases significantly with increasing temperature.

It should be noted here that the minimum in the % RA and % elongation ductility parameters for the PWHT material does not occur within the temperature regime of serrated flow. Such behaviour for carbon steels has been reported by other workers/8,14/. For example, Bailey/8/ reported that for some simulated weld repair weld metals in some C-Mn and Mn-Ni-Mo pressure vessel steels, the maximum reduction in ductility (defined by author as sum of % RA and % elongation) occurred at a temperature where smooth load vs extension curves were normally obtained. In addition, de Morton/14/ reported that the minimum RA values in a plate steel were obtained just above the maximum temperature for serrated flow, although the minimum elongation fell within the temperature range for jerky flow.

5.0 CONCLUSIONS

1. Serrated or jerky flow was observed in tensile testing of both AW and PWHT PN-229 weld materials under a constant applied strain rate of 1×10^{-3} s^{-1}. In the AW material serrated flow was observed at test temperatures in the range 150-250°C. For the PWHT material, serrated flow was only observed at temperatures in the range 200-250°C.

2. The 0.2% offset yield strength of the AW material decreases approximately linearly with increasing temperature over the temperature range 20-200°C. From 200-350°C, the decrease is also nearly linear, with the rate of decrease greater than that at the lower temperature range.

3. The 0.2% offset yield strength of the PWHT material also decreases with increasing temperature. However, the rate of decrease is not linear and between 250 and 350°C the rate of decrease is minimal.

4. The tensile strength vs temperature plot for the AW material exhibits a pronounced local maximum at about 200°C. Between 150 and 350°C, the tensile strength of the AW material was 10-30% higher than that found at ambient temperature.

5. The tensile strength vs temperature curve for the PWHT material exhibits a local minimum at about 200°C and a local maximum at about 350°C. The shape of the curve is similar to that observed for the parent SA106B piping material.

6. The % RA and % elongation vs temperature plots for the AW material exhibit minimum values at about 200 and 150°C, respectively.

7. The % RA and % elongation vs temperature plots for the PWHT material exhibit minimum values at about 350 and 300°C, respectively. However, these minima are much more shallow than those observed for the AW material.

8. Based on the tensile test data obtained in this study, the AW and PWHT PN-229 materials should exhibit minimum fracture toughness properties at temperatures in the range 150-200°C and 300-350°C, respectively.

6.0 ACKNOWLEDGEMENTS

The weldments used in the present study were supplied by M.L. Lau of the Mechanical Design Department of the Design and Development - Generation Division. The test coupon, 2A, was fabricated according to a combination of weld procedures (consistent with OH weld procedure PN-229-85) specified by C. Gluck of the Mechanical Design Department of the Design and Development - Generation Division.

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TABLE I

SUMMARY OF TENSILE RESULTS FOR AW AND PWHT PN-229 MATERIALS

TEST	MATERIAL	TEMP (°C)	$\dot{\epsilon}_a$ (s^{-1})	0.2% YS (MPa)	UTS (MPa)	%RA	% ELONG	SERRATED FLOW (Y/N)
CSW1	AW-1A	20	1×10^{-3}	390	493.4	71.3	30.6	N
CSW34	AW-2A	20	"	407	505.3	65.6	27.9	N
JVK21	AW-2A	20	"	383	473.3	69.3	29.5	N
JVK24	AW-2A	60	"	393	484.5	69.3	26.8	N
JVK19	AW-2A	100	"	390	485.4	65.3	23.2	N
JVK23	AW-2A	125	"	384	549.4	57.4	21.8	N
JVK18	AW-2A	150	"	379	592.9	53.0	19.0	Y
JVK25	AW-2A	150	"	387	606.1	50.5	18.6	Y
CSW11	AW-1A	200	"	364	626.1	55.0	20.6	Y
JVK17	AW-2A	200	"	395	632.5	52.0	21.1	Y
CSW14	AW-1A	250	"	354	614.5	52.2	22.7	Y
CSW17	AW-1A	300	"	312	592.3	58.0	30.1	N
JVK22	AW-2A	300	"	326	591.6	52.4	27.3	N
JVK20	AW-2A	350	"	309	554.2	63.3	28.0	N
CSW2	PWHT-1A	20	"	314	452.1	71.5	30.6	N
CSW7	PWHT-1A	20	"	318	451.0	67.7	35.5	N
CSW35	PWHT-2A	20	"	327	453.6	71.6	31.8	N
JVK31*	PWHT-2A	60	"	312	429.2	--	--	N
JVK27	PWHT-2A	100	"	304	410.5	73.1	30.6	N
JVK28	PWHT-2A	150	"	286	406.8	71.3	30.3	N
CSW20	PWHT-1A	200	"	261	394.0	69.0	29.7	Y
JVK26	PWHT-2A	200	"	266	401.9	71.5	27.4	Y
JVK29	PWHT-2A	250	"	239	408.9	70.4	27.0	Y
JVK30	PWHT-2A	300	"	236	433.7	67.1	25.4	Y
JVK33	PWHT-2A	300	"	230	423.3	67.1	24.9	N
JVK34	PWHT-2A	300	"	231	431.6	68.2	27.5	N
JVK32	PWHT-2A	350	"	229§	438.2	67.1	30.1	N
JVK35	PWHT-2A	400	"	212	397.0	72.1	35.2	N

* Test terminated before sample failure
§ Estimated from load vs extension curve

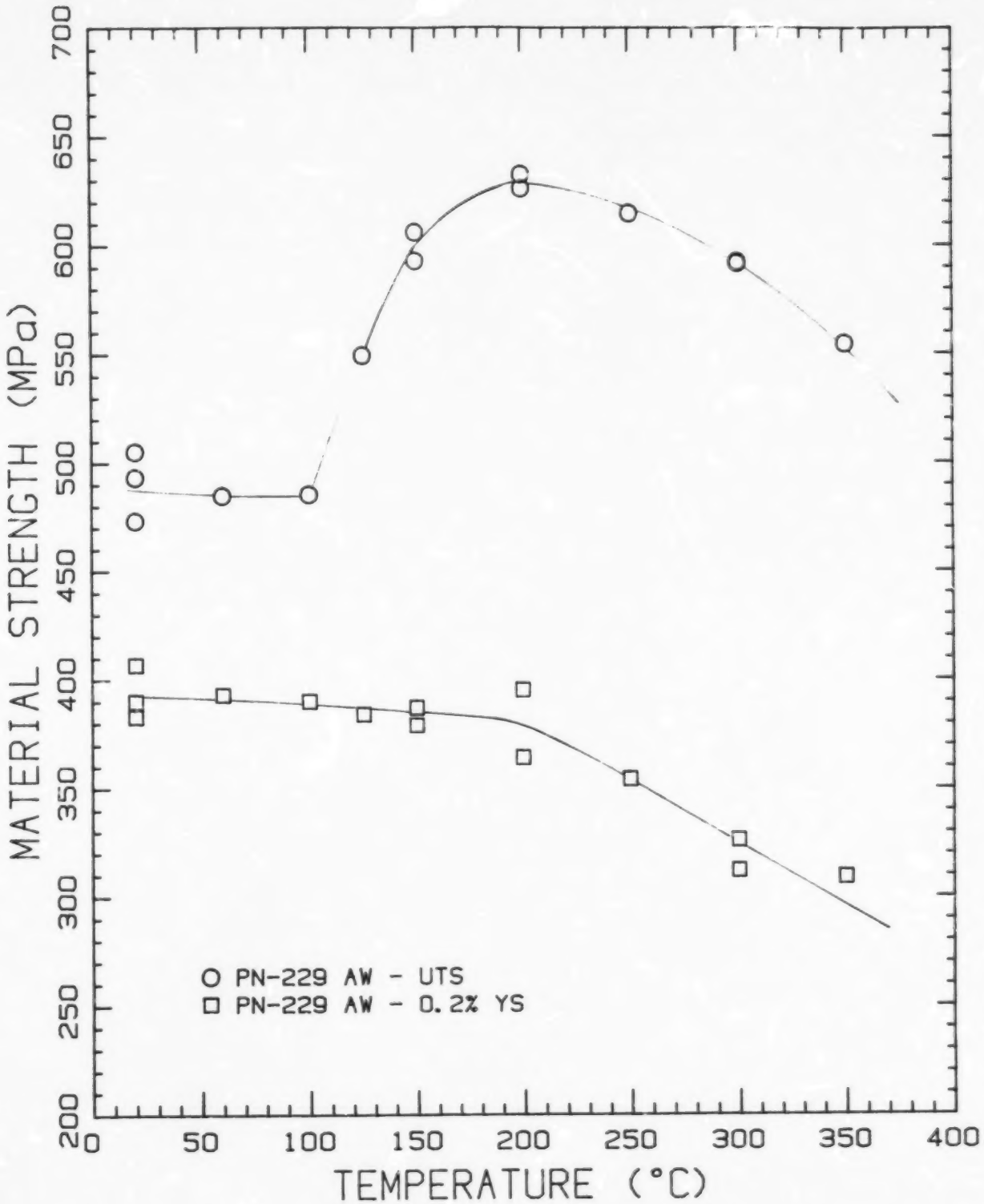

FIGURE 1: PLOTS ILLUSTRATING THE VARIATION OF 0.2% OFFSET YIELD STRENGTH AND TENSILE STRENGTH WITH TEMPERATURE IN AW PN-229 WELD METAL UNDER A CONSTANT APPLIED STRAIN RATE OF 1E-3 1/S.

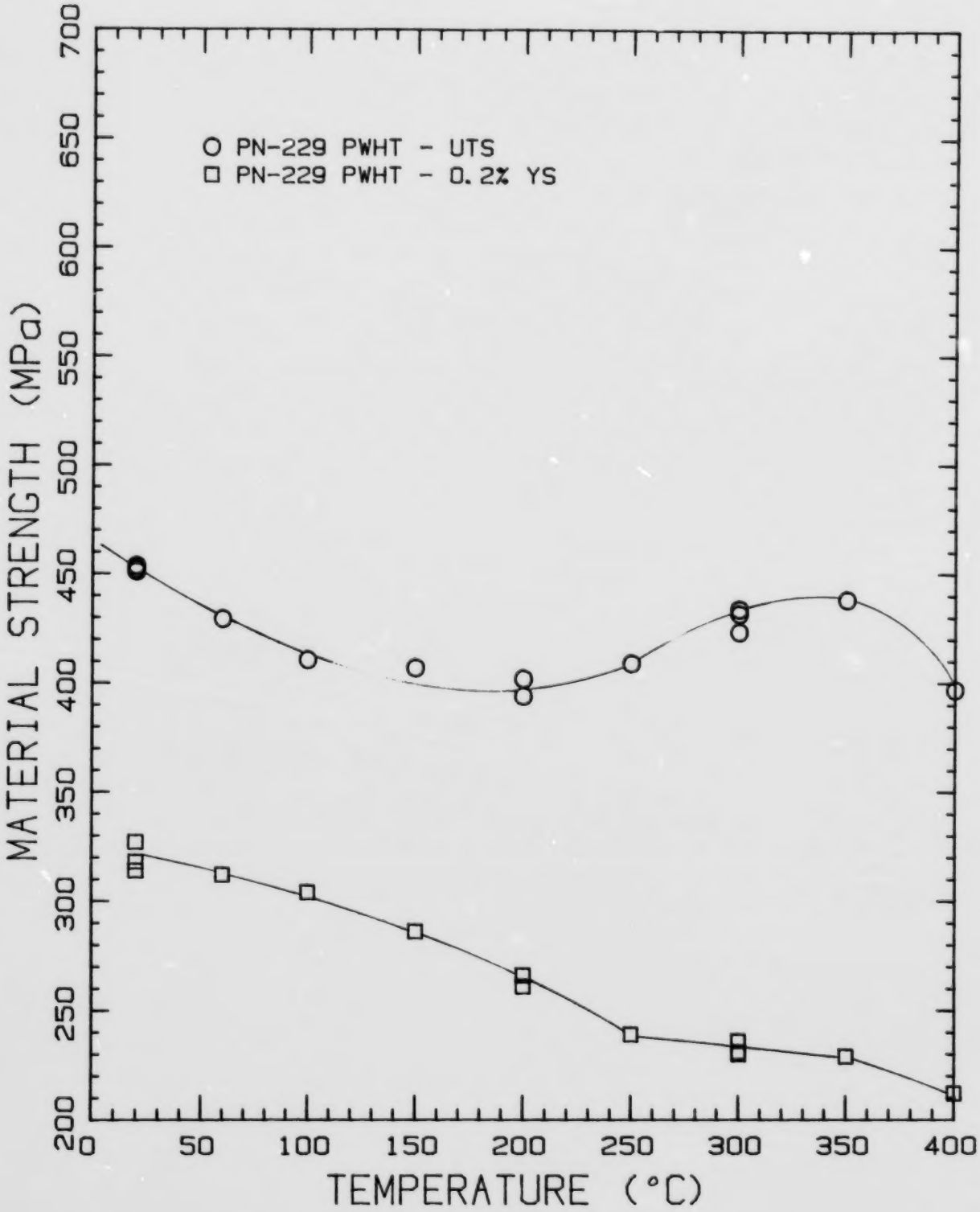

FIGURE 2: PLOTS ILLUSTRATING THE VARIATION OF 0.2% OFFSET YIELD STRENGTH AND TENSILE STRENGTH WITH TEMPERATURE IN PWHT PN-229 WELD METAL UNDER A CONSTANT APPLIED STRAIN RATE OF 1E-3 1/S.

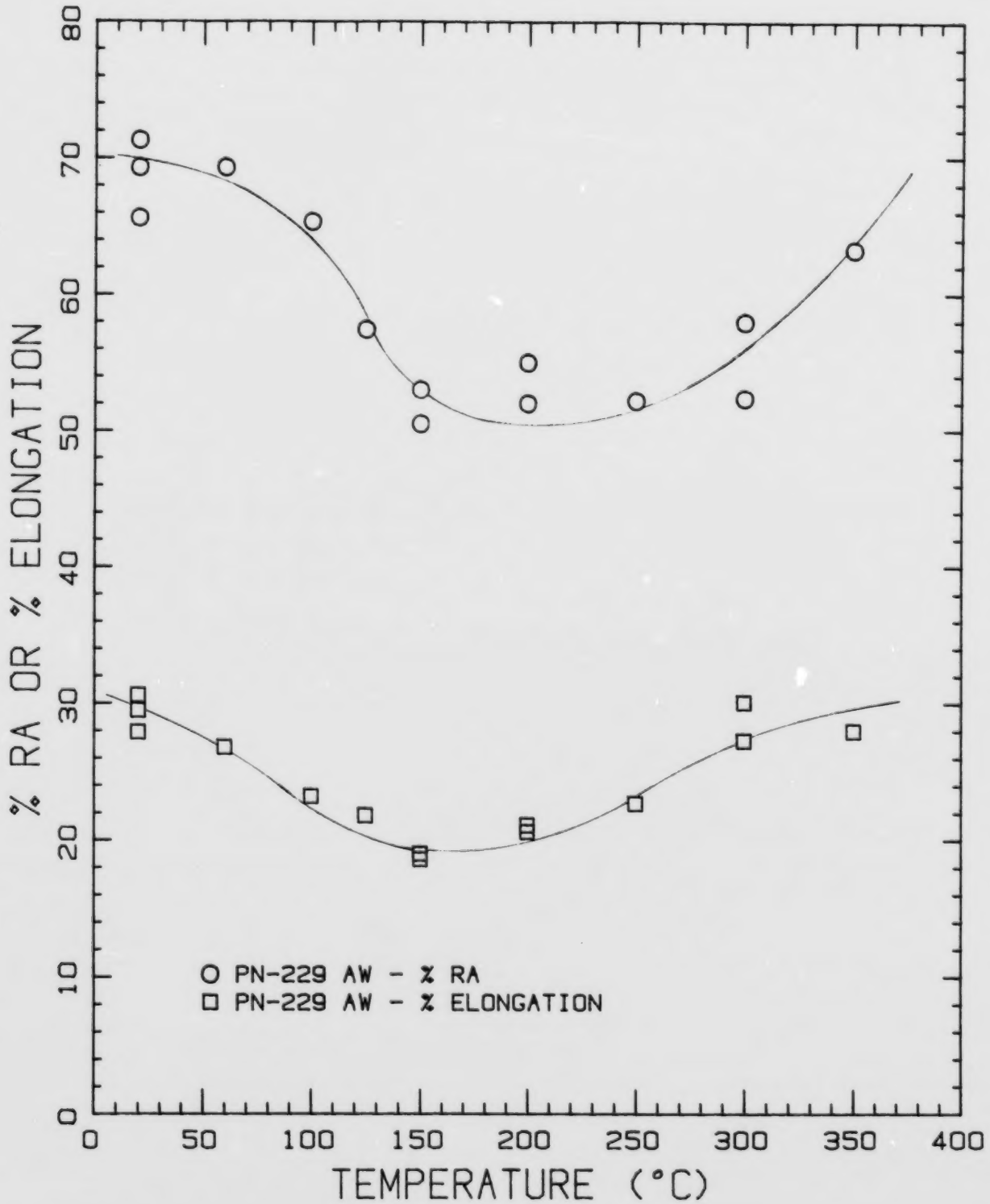

FIGURE 3: PLOTS ILLUSTRATING THE VARIATION OF % RA AND % ELONGATION WITH TEMPERATURE IN AW PN-229 WELD METAL UNDER A CONSTANT APPLIED STRAIN RATE OF 1E-3 1/S.

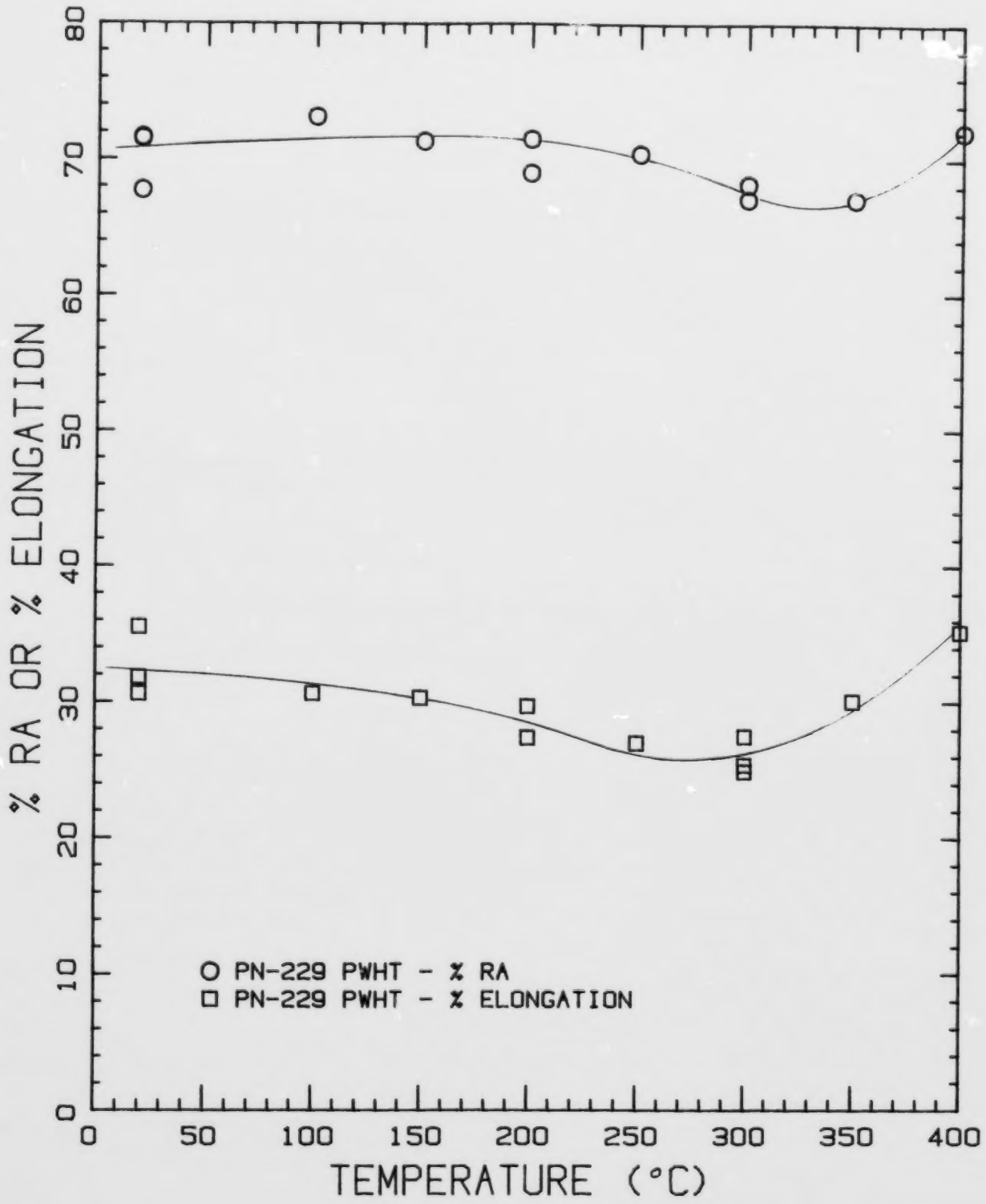

FIGURE 4: PLOTS ILLUSTRATING THE VARIATION OF % RA AND % ELONGATION WITH TEMPERATURE IN PWHT PN-229 WELD METAL UNDER A CONSTANT APPLIED STRAIN RATE OF 1E-3 1/S.